

TDRSS DEMAND ACCESS SERVICE: APPLICATION OF ADVANCED TECHNOLOGY TO ENHANCE USER OPERATIONS

David J. Zillig*, D. Robert McOmber**, and Neil Fox***

**NASA/GSFC, Microwave Systems Branch, Code 567, Greenbelt, MD 20771
Phone: (301) 286-8003, Fax: (301) 286-1724, e-mail: David.J.Zillig@gsfc.nasa.gov*

***Stanford Telecom, 1761 Business Center Drive, Suite 200, Reston, VA 20190
Phone: (703) 438-8064, Fax: (703) 438-8112, e-mail: rmcomber@sed.stel.com*

****Stanford Telecom, 1761 Business Center Drive, Suite 200, Reston, VA 20190
Phone: (703) 438-7843, Fax: (703) 438-8112, e-mail: nfox@sed.stel.com*

ABSTRACT

Current operations of the NASA Tracking and Data Relay Satellite System (TDRSS) provide access to services based on a service schedule which is generated from user requests. Normally completed days in advance, this schedule is based upon estimates of user needs and mission event timelines. The desire to provide service to smaller missions and at reduced cost makes implementation of efficient service allocation approaches desirable. Fortunately, technology advances occurring over the past several years now make it possible to enhance TDRSS Multiple Access operations to such an extent that service on demand is now achievable. In particular, hardware advances permitting implementation of very low cost beamformers and receivers can permit augmentation of the MA return link capability to provide each TDRSS user with a dedicated return link antenna beam for communications. Additionally, incorporation of new ground station equipment will greatly enhance operations for the MA forward link shared resource. This paper provides an overview of the technologies that enable this new TDRSS service capability and describes the significant benefits to user operations arising from the Demand Access service.

1 INTRODUCTION

NASA uses the Space Network, which includes the TDRSS, to provide reliable low- and high-data rate relay services between user spacecraft in Earth orbit and the ground. TDRSS consists of several communication spacecraft in geostationary orbit as well as ground terminals located at the White Sands Complex (WSC) in White Sands, New Mexico. TDRSS provides forward (user control center-to-user spacecraft) services, which include satellite and instrument commanding, and return (user spacecraft-to-user control center) services, which include both science data and satellite telemetry. TDRSS provides these functions via both a Single Access service, which uses high gain antennas on the TDRS to achieve data rates up to 300 Mbps, or a Multiple Access (MA) service, which uses a phased array antenna that can support commanding to one user or low-rate science data and telemetry from several users simultaneously. This phased array antenna implementation is unique in that return link array beamforming is performed on the ground rather than on board the TDRS spacecraft. Figure 1 provides an overview of one TDRS.

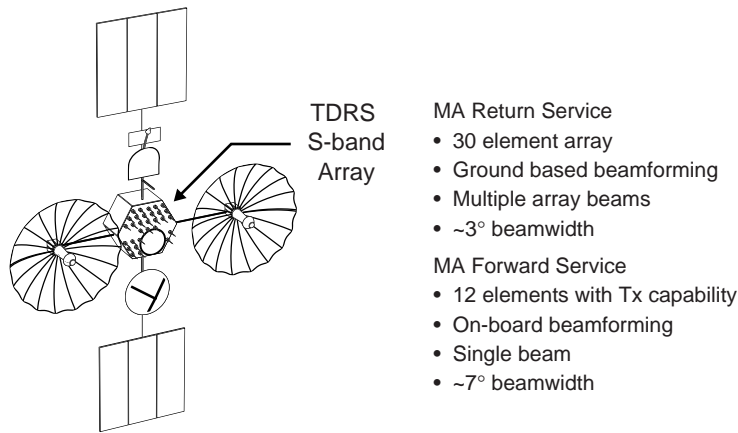


Figure 1: A Tracking and Data Relay Satellite (TDRS)

Current operations of TDRSS provide access to services based on a schedule of the available communications links which is generated from user requests. Normally completed days in advance, this schedule is based upon estimates of user needs and mission event timelines. The desire to provide service to smaller missions and at reduced cost makes implementation of efficient service allocation approaches desirable. TDRSS users have additionally expressed an interest in new, innovative service types such as spacecraft initiated emergency notifications and science alerts. Fortunately, technology advances occurring over the past several years now make it possible to enhance TDRSS Multiple Access operations to such an extent that service on demand is now achievable. In particular, hardware advances permitting implementation of very low cost beamformers and receivers can permit augmentation of the MA return link capability to provide each TDRSS user with a dedicated return link antenna beam for communications. Additionally, incorporation of new ground station equipment will greatly enhance operations for the MA forward link shared resource.

This Demand Access (DA) concept will automate service on demand, providing substantial benefits to TDRSS users and the TDRSS Network at low cost and with no changes to either the TDRS or user spacecraft [1]. In this paper, the TDRSS Demand Access capability now under development is presented. Key technology advances that enable the Demand Access implementation are defined and the substantial benefits to user operations brought about by these changes are described.

2 THE CURRENT MA RETURN LINK ARCHITECTURE

The WSC contains distinct equipment clusters (called Space Ground Link Terminals or SGLTs) for each TDRS supported. Four SGLTs within the existing WSC support the MA service along with another SGLT under development in Guam). Together two TDRS spacecraft supported by the WSC SGLTs along with a TDRS supported by the Guam terminal can provide full-time line-of-sight visibility to most Earth orbiting users.

As mentioned above, the MA return link service from a user spacecraft to a TDRS is supported using a phased array antenna on-board the TDRS. This 30 element, S-band phased array is unique in that the phase shifting and combining operations necessary for beamforming are not performed on board the TDRS. Instead, the 30 element channels of received user data are frequency division multiplexed (FDM) then transmitted to the TDRS ground terminal where beamforming and signal demodulation are ultimately performed. Using multiple sets of beamforming equipment and associated demodulators within a single SGLT, and taking advantage of the fact that user signals are spread

spectrum with unique pseudo-noise (PN) codes, permits the TDRS to support multiple simultaneous users via a CDMA architecture.

Figure 2 provides an overview of the currently existing TDRSS MA return link architecture showing relevant equipment within a single WSC SGLT along with an outline of the data flow to the user control centers. Within the SGLT, the 30 FDM MA return channels from a single TDRS are first separated into 30 analog channels at a common intermediate frequency by the Element Separator. Next, each of the 30 channels is digitized within the A/D Quad Splitter and output as two channels of 8-bit digital data representing In-phase and Quadrature components sampled at 8.5 Msps. These 60 digital channels are then distributed to each beamformer/receiver.

As illustrated, a single WSC SGLT supporting MA return service contains six beamformer/receiver combinations. Of these six, five are made available for user service and one set of equipment is dedicated to array calibration. Thus five simultaneous MA return link users can be supported and each user receives the full gain of the TDRS phased array. These five links per TDRS have been fully adequate to support the community of orbiting spacecraft using an operations concept based on prior scheduling. But, as described below, new operations concepts become feasible if more return links can be provided.

3 THE RETURN LINK DA CONCEPT

3.1 STATEMENT OF NEED

The evolution towards smaller, lower cost space missions has led to an increased user need for streamlined mission support and a strong desire for autonomous spacecraft operation. Toward these goals, NASA GSFC has investigated and initiated implementation of a substantial change to the TDRSS MA return link service. Through an expansion of the MA service, users desiring such a capability will be able to obtain a continuously available MA return link to their spacecraft. Not only can the previous scheduling process be largely bypassed by users needing reduced operational complexity but, for the first time, it will be possible for a user spacecraft to initiate TDRSS return link communications without prior coordination by the user operations center. These changes will be implemented by expanding the number of MA return links available on the current TDRSS spacecraft and providing appropriate control/data routing equipment.

3.2 TECHNICAL APPROACH

The combination of array beamforming and user signal PN spreading provides a high degree of separation among user signals within an MA return link demodulator. The TDRS architecture, if provided with sufficient beamformers and demodulators, could support a large number of return link users provided that individual user data rates are sufficiently low (hundreds of users at 1-10 kbps – depending on user duty cycle).

In the past, costs associated with such expansion of the MA return service capability were prohibitive. The current WSC beamformers were implemented with 1980's technology and each beamformer requires 30 circuit cards and occupies one full chassis of a 30 inch wide equipment rack. To understand the need for this level of complexity, consider that each beamformer receives a complete copy of the sampled data for all 30 array elements: 60 sampled channels (for I and Q) x 8 bits per sample x 8.5 Msps gives 4.08 Gbps processed by each beamformer. While the phase shifting and combining within each beamformer are not complicated operations, the data handling operations

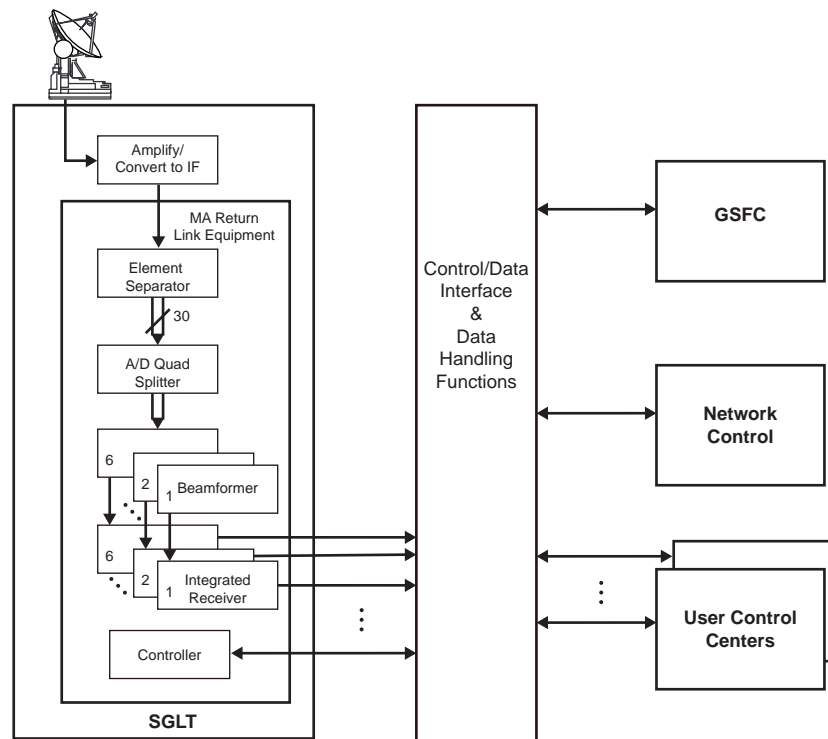


Figure 2: The Existing MA Return Link Architecture

required to deal with this volume of data (both moving it among the individual circuit cards of a beamformer, and transporting it to all beamformers) are quite complex. Additionally, to meet redundancy requirements, each beamformer was further burdened by the need to perform a set of calculations (noise covariance matrix estimation) that were common to all the beamformers.

The 1990's have brought about substantial evolution in both digital processors and in data networking equipment. Taking advantage of these advancements, development of a new generation TDRSS beamformer has been initiated. The new beamformer implementation is expected to achieve a factor of five reduction in beamformer size and nearly a factor of ten reduction in per unit costs.

Figure 3 provides an overview of the new beamformer architecture that emphasizes the signal multiplexing architecture. As a key first step in the development of the new beamformer concept, functionality was split between an Element Multiplexer/Correlator (EMC) unit and Individual Beamformer Units (IBUs). The EMC accepts the element data from the existing WSC A/D Quad Splitter, performs those calculations that were previously common to all beamformers, and distributes all beamforming data to the IBUs. Data distribution relies on a commercial off-the-shelf Network Transparent Switch (NTS). Data from six array elements is time division multiplexed together (giving five groups of six elements) then fed to the NTS for distribution to IBU Groups (IBUGs) containing five IBUs. Each IBUG contains a matching NTS receiver which demultiplexes the TDM data and distributes it to the IBUs.

The NTS, in conjunction with modern high speed digital processing, greatly facilitates the beamformer implementation. A single EMC can support fifteen IBUGs for a total of 75 IBUs in the illustrated configuration. It is also possible, however, to use a single output from the EMC Network Transparent Switch transmitter to feed a distribution unit (based again on the same NTS switch) that regenerates the data for transmission to still more IBUGs. This flexible architecture can support hundreds of beamformers per SGLT – far more than are currently anticipated.

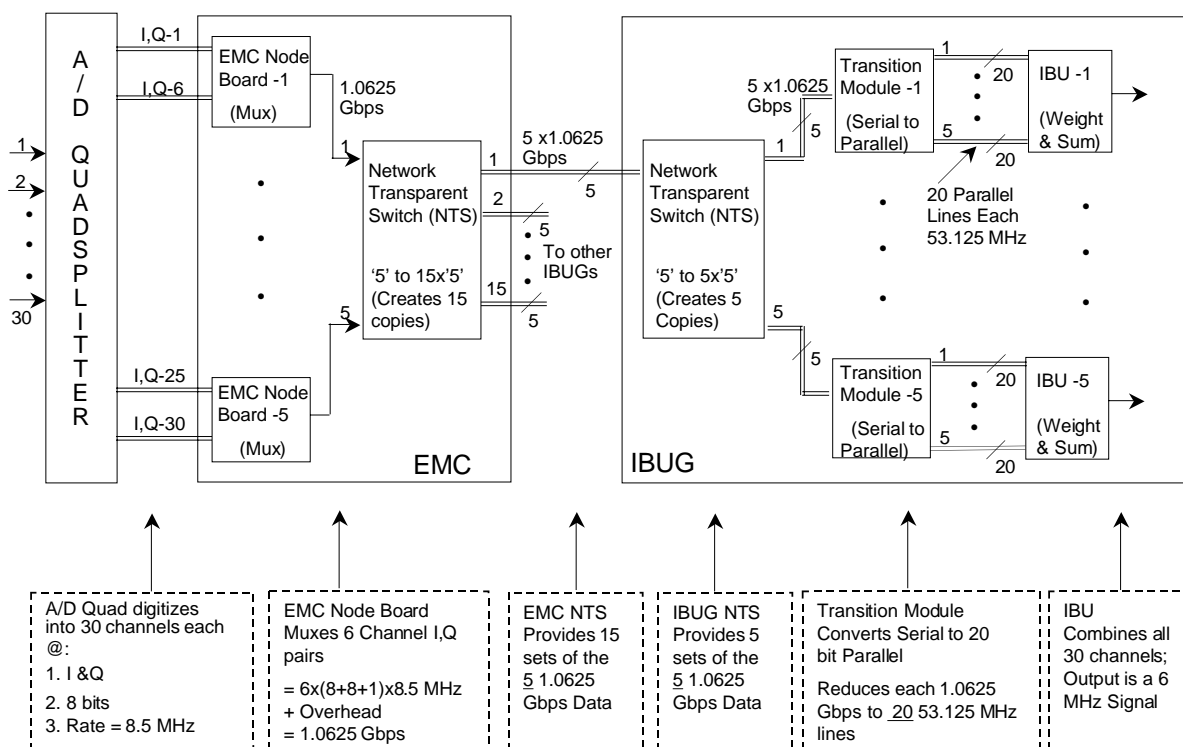


Figure 3: The Beamformer Signal Multiplexing Architecture

Demand Access demodulators will also be relatively inexpensive and much smaller than the current units and will also offer some performance improvements relative to the current WSC demodulators. Not only will the demodulator realize cost improvements due to advances in technology since the 1980s, the relatively large number of demodulators that will be produced will lower production costs by distributing non-recurring engineering costs over more units.

One potential performance gain is in acquisition time. The ongoing NASA demodulator prototyping effort has centered around Charge Coupled Device (CCD) technology which allows rapid PN code correlation evaluations in the analog domain.

Figure 4 illustrates the planned architecture of the new beamformers and demodulators within an SGLT of the WSC. The existing A/D Quad Splitters of the WSC have spare outputs available for connection of the new equipment. Existing beamformers and receivers within the WSC will not be affected by the service expansion. Automatic data routing (not illustrated) of all received MA return link data to the appropriate user control center is planned.

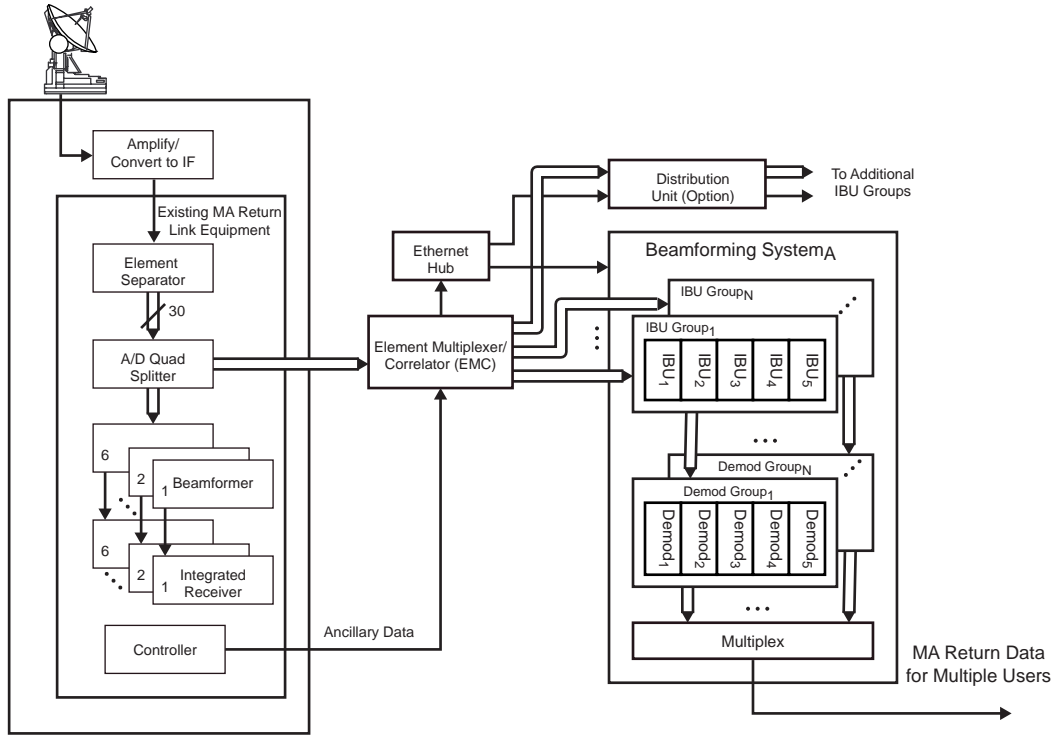


Figure 4: The Return Link Demand Access Architecture

3.3 MA RETURN DA OPERATIONS CONCEPTS

Implementation of large numbers of beamformer/demodulator combinations in the MA Return DA architecture will permit users desiring a continuously available return link to attain this goal by having a dedicated beamformer/receiver combination on each of three TDRSS SGLTs. The user spacecraft need not transmit continuously. Only the ground equipment will be continuously configured – able to receive and demodulate user return data whenever the user spacecraft transmits. Figure 5 illustrates some of the operations scenarios supported by the new architecture. These are:

1. Normal MA Return Service without Scheduling. It must be emphasized that the DA architecture does not preclude use of the MA return link in its traditional role for support of planned user service events.
2. Unplanned Return Transmission. For the first time, in the TDRSS system, user spacecraft will be able to initiate return service without prior coordination/planning by the user operations center. Low-cost, autonomous spacecraft collecting science data will be able to return that data whenever necessary (either via the MA return link or by using the DA service to request a higher rate service). Data may be immediately returned from unpredictable targets of opportunity (such as astronomical events). Another key application of spacecraft initiated service is the ability of the user spacecraft to immediately notify the mission operations center in the event of an anomaly or emergency situation. This option has generated considerable interest among users that plan to use TDRSS services.
3. Non-Space User Data Collection. With proper frequency coordination, the TDRSS architecture can provide support to non-space users. Because the TDRSS MA return link

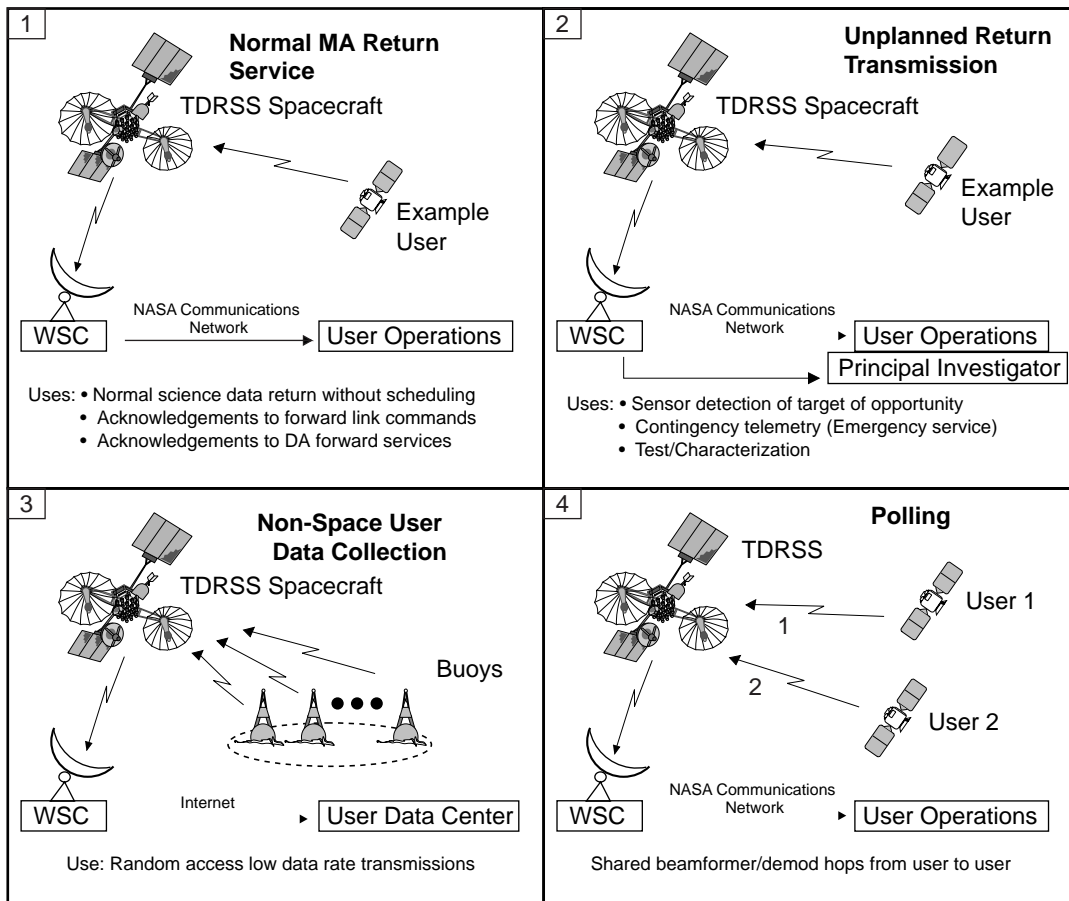


Figure 5: Return Link DA Operations Concepts

antenna beam (with 3.2° beamwidth) covers a large footprint on the Earth, there is the possibility of supporting a large community of low duty cycle users within the footprint of a single beamformer. Using multiple demodulators connected to a single beamformer would permit simultaneous service by a number of low data rate users.

4. **Polling.** Another possibility currently under consideration is MA return link polling. For those users desiring the benefits of spacecraft initiated service that cannot afford dedicated beamformers, a beamformer/demodulator shared with other users could be used. By periodically scanning the community of users participating in this service, a user spacecraft transmitting data can be identified and then handed off to another beamformer/demodulator for data extraction. The efficiency of such a service depends on the number of users participating and their requirements for return link service.

4 THE FORWARD LINK DA CONCEPT

While a TDRS can support multiple simultaneous MA return link services, only a single MA forward (TDRS-to-user spacecraft) link is supported per TDRS spacecraft. For this reason, the MA forward link DA service concept focuses on efficient allocation of the MA forward link among TDRS users rather than on technology to expand the existing service capability. The forward link DA concept will automate the user service request process for MA forward service – allocating service to users on a first-come first-served basis. For short duration user services (<10 minutes) there is a high probability

that individual users will obtain the forward link without the need to wait for other user services to complete.

While the forward DA implementation does not rely on state-of-the-art technology, it should be noted that standard interfaces and protocols will be used wherever feasible within the architecture. The use of standardized approaches to the user interface, provide substantial cost and operational advantages to the user community that were not possible when the TDRSS was conceived in the 1970s.

5 SUMMARY

This paper has shown how incorporation of new technologies into an existing satellite communications architecture can not only enhance user operations, but also make available new user operations concepts not originally conceived by the system implementers. The new Demand Access Service capabilities should be available to the community of TDRSS users in 2000.

REFERENCE

1. D. Zillig, R.McOmber, & W.D. Horne, "Demand Access Service for TDRSS Users," AIAA 16th International Communications Satellite Systems Conference, Washington, DC, 25-29 February 1996